CLAIMS

1. A method for producing Group-III-element nitride single crystal, comprising:

reacting at least one Group III element selected from the group consisting of gallium (Ga), aluminum (Al), and indium (In) with nitrogen (N) in a mixed flux containing sodium (Na) and at least one of an alkali metal (other than Na) and an alkaline-earth metal, thereby causing Group-III-element nitride single crystal to grow.

2. The method according to claim 1, wherein the Group III element is gallium (Ga), and the Group-III-element nitride single crystal is gallium (Ga) nitride single crystal.

3. The method according to claim 1, wherein the alkali metal is at least one selected from the group consisting of lithium (Li), potassium (K), rubidium (Rb), cesium (Cs), and francium (Fr), and the alkaline-earth metal is at least one selected from the group consisting of calcium (Ca), strontium (Sr), barium (Br), and radium (Ra).

4. The method according to claim 1, wherein the mixed flux is a mixed flux of sodium and calcium.

5. The method according to claim 4, wherein a ratio of the calcium (Ca) to the total of the sodium (Na) and the calcium (Ca) is in a range from 0.1 to 99 mol%.

6. The method according to claim 1, wherein the mixed flux is a mixed flux of sodium (Na) and lithium (Li).

7. The method according to claim 6, wherein a ratio of the lithium (Li) to the total of the sodium (Na) and the lithium is in a range from 0.1 to 99 mol%.

8. The method according to claim 1, wherein the reaction is carried out under conditions of a temperature of 100°C to 1200°C and a pressure of 100 Pa to 200 MPa.

9. The method according to claim 1, wherein nitrogen (N) containing gas is used as a nitrogen source.

10. The method according to claim 9, wherein the nitrogen (N) containing gas is at least one of nitrogen (N_2) gas and ammonia (NH_3) gas.

11. The method according to claim 9, wherein the nitrogen (N) containing gas is ammonia (NH_3) gas or a mixed gas containing the ammonia (NH_3) gas and nitrogen (N) gas.

12. The method according to claim 1, wherein a Group-III-element nitride is provided beforehand, and the Group-III-element nitride is brought into contact with the mixed flux to cause new Group-III-element nitride single crystal to grow using the Group-III-element nitride as a nucleus.

13. The method according to claim 12, wherein the Group-III-element nitride that serves as the nucleus is single crystal or amorphous.

14. The method according to claim 12, wherein the Group-III-element nitride that serves as the nucleus is in a form of a thin film.

15. The method according to claim 14, wherein the thin film is formed on a substrate.

16. The method according to claim 1, wherein the mixed flux contains an impurity as a dopant.

17. The method according to claim 16, wherein the impurity is at least one selected from the group consisting of carbon (C), oxygen (O), silicon (Si), alumina (Al_2O_3), indium (In), aluminum (Al), indium nitride (InN), silicon oxide (SiO_2), indium oxide (In_2O_3), zinc (Zn), magnesium (Mg), zinc oxide (ZnO), magnesium oxide (MgO), and germanium (Ge).

18. The method according to claim 1, which causes transparent single crystal to grow.

19. A method for producing Group-III-element nitride single crystal,

comprising: reacting at least one Group III element selected from the group consisting of gallium (Ga), aluminum (Al), and indium (In) with nitrogen (N) in a metal flux containing at least one of an alkali metal and an alkaline-earth metal, thereby causing Group-III-element nitride single crystal to grow,

wherein a Group-III-element nitride is provided beforehand, and the Group-III-element nitride is brought into contact with the metal flux to cause new Group-III-element nitride single crystal to grow using the Group-III-element nitride as a nucleus.

20. The method according to claim 19, wherein the Group III element is gallium (Ga), and the Group-III-element nitride single crystal is gallium (Ga) nitride single crystal.

21. The method according to claim 19, wherein the Group-III-element nitride that serves as the nucleus is single crystal or amorphous.

22. The method according to claim 21, wherein the Group-III-element nitride that serves as the nucleus is in a form of a thin film.

23. The method according to claim 22, wherein the thin film is formed on a substrate.

24. The method according to claim 19, wherein the Group-III-element nitride that serves as the nucleus has a maximum diameter of at least 2 cm.

25. The method according to claim 19, wherein the Group-III-element nitride that serves as the nucleus has a maximum diameter of at least 3 cm.

26. The method according to claim 19, wherein the Group-III-element nitride that serves as the nucleus has a maximum diameter of at least 4 cm.

27. The method according to claim 19, wherein the Group-III-element nitride that serves as the nucleus has a maximum diameter of at least 5 cm.

28. The method according to claim 19, wherein a nitride is present in the flux at least at an initial stage of the reaction.

29. The method according to claim 28, wherein the nitride is at least one selected from the group consisting of Ca_3N_2, Li_3N, NaN_3, BN, Si_3N_4, and InN.

30. The method according to claim 19, wherein the flux contains an impurity as a dopant.

31. The method according to claim 30, wherein the impurity is at least one selected from the group consisting of carbon(C), oxygen (O), silicon (Si), alumina (Al_2O_3), indium (In), aluminum (Al), indium nitride (InN), silicon oxide (SiO_2), indium oxide (In_2O_3), zinc (Zn), magnesium (Mg), zinc oxide (ZnO), magnesium oxide (MgO), and germanium (Ge).

32. The method according to claim 19, wherein the alkali metal is at least one selected from the group consisting of lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), and francium (Fr), and the alkaline-earth metal is at least one selected from the group consisting of calcium (Ca), strontium (Sr), barium (Br), and radium (Ra).

33. The method according to claim 19, which causes transparent single crystal to grow.

34. Group-III-element nitride transparent single crystal obtained by the method according to any one of claims 1 to 33.

35. Group-III-element nitride transparent single crystal in bulk size, having a dislocation density of $10^5/cm^2$ or less and a maximum diameter of at least 2 cm.

36. The single crystal according to claim 35, having a dislocation density of $10^4/cm^2$ or less.

37. The single crystal according to claim 35, having a dislocation density of $10^3/cm^2$ or less.

38. The single crystal according to claim 35, having a dislocation density of $10^2/cm^2$ or less.

39. The single crystal according to claim 35, having a dislocation density of $10^1/cm^2$ or less.

40. Group-III-element nitride transparent single crystal in bulk size, having a dislocation density of $10^5/cm^2$ or less and a maximum diameter of at least 3 cm.

41. The single crystal according to claim 40, having a maximum diameter of at least 4 cm.

42. The single crystal according to claim 40, having a maximum diameter of at least 5 cm.

43. Group-III-element nitride transparent single crystal in bulk size, having a dislocation density of $10^4/cm^2$ or less and a maximum diameter of at least 5 cm.

44. The single crystal according to claim 43, having a dislocation density of $10^3/cm^2$ or less.

45. The single crystal according to claim 43, having a dislocation density of $10^2/cm^2$ or less.

46. The single crystal according to claim 43, having a dislocation density of $10^1/cm^2$ or less.

47. A semiconductor device comprising the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

48. A semiconductor device comprising a semiconductor layer,

wherein the semiconductor layer is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

49. A semiconductor device comprising a p-type semiconductor layer and an n-type semiconductor layer that are joined to each other,

wherein at least one of the semiconductor layers is formed of the Group-III-element nitride transparent single crystal according to any one of

claims 34 to 46.

50. A semiconductor device comprising at least one semiconductor element selected from an npn-type transistor element, a pnp-type transistor element, and an npnp thyristor,

wherein at least one semiconductor layer used in the semiconductor element is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

51. A semiconductor device comprising a field-effect transistor element, the field-effect transistor element comprising an insulating semiconductor layer, a conductive semiconductor layer formed on the insulating semiconductor layer, and a source electrode, a gate electrode, and a drain electrode that are formed on the conductive semiconductor layer,

wherein at least one of the insulating semiconductor layer and the conductive semiconductor layer is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

52. The semiconductor device according to claim 51, further comprising a substrate,

wherein the field-effect transistor element is formed on the substrate, and the substrate is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

53. A semiconductor device comprising a light emitting diode (LED) element, the light emitting diode (LED) element comprising an n-type semiconductor layer, an active region layer, and a p-type semiconductor layer that are laminated in this order,

wherein at least one of the three layers is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

54. The semiconductor device according to claim 53, further comprising a substrate,

wherein the light emitting diode element is formed on the substrate, and the substrate is formed of the Group-III-element nitride transparent single crystal according to any one of claims 33 to 38.

55. A semiconductor device comprising a semiconductor laser diode (LD) element, the semiconductor laser diode (LD) element comprising an n-type semiconductor layer, an active region layer, and a p-type semiconductor layer that are laminated in this order,

wherein at least one of the three layers is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

56. The semiconductor device according to claim 55, further comprising a substrate,

wherein the semiconductor laser diode element is formed on the substrate, and the substrate is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

57. A semiconductor device comprising an optical sensor element, the optical sensor element comprising a p-type semiconductor layer and an n-type semiconductor layer that are joined to each other,

wherein at least one of the semiconductor layers is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

58. The semiconductor device according to claim 57, further comprising a substrate,

wherein the optical sensor element is formed on the substrate, and the substrate is formed of the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46.

59. The semiconductor device according to any one of claims 47 to 58, further comprising a Group-III-element nitride thin film that is grown by using the Group-III-element nitride transparent single crystal according to any one of claims 34 to 46 as a substrate.

60. The semiconductor device according to claim 59, wherein the Group-III-element nitride on the substrate is grown by MOVPE.